An Instrument to Enable Identification of Anthropogenic CO2 Emissions Using Concurrent CO Measurements

LaRC
GATS, Inc.
NIA

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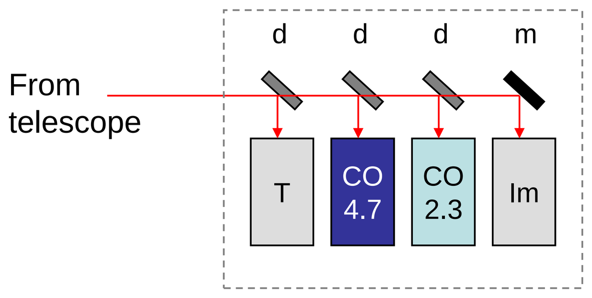
The ASCENDS measurement concept

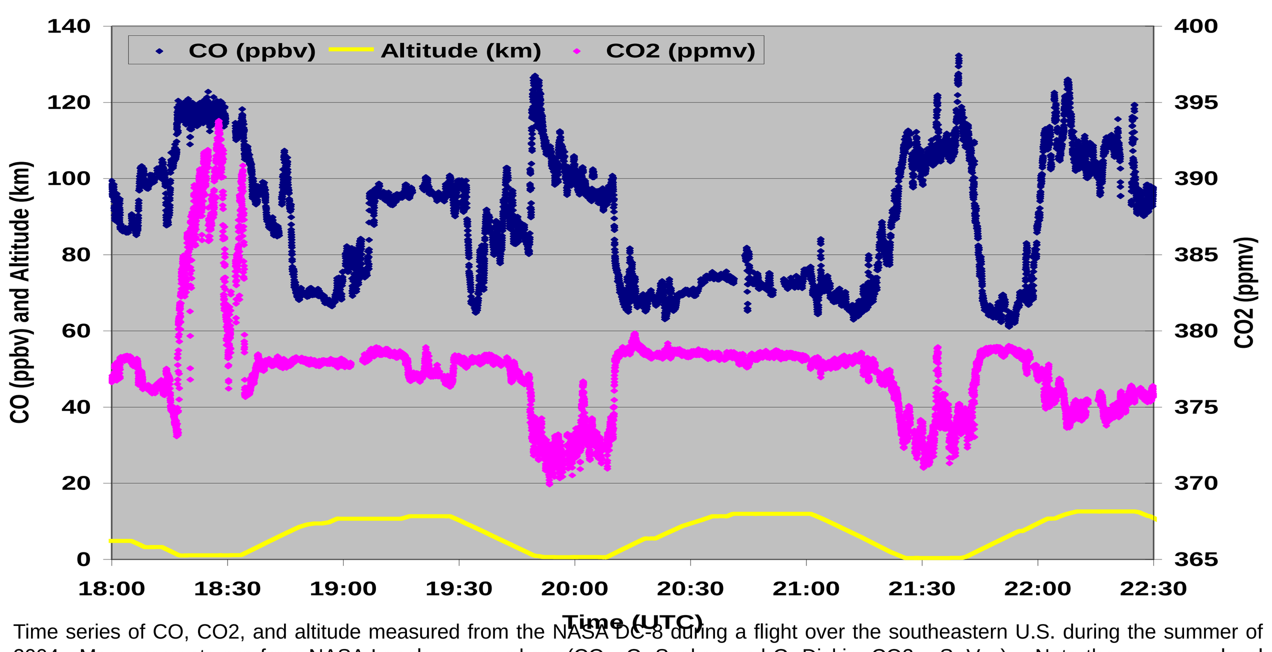
In order to separate physiological fluxes from biomass burning and fossil fuel use, the NRC report Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond requires ASCENDS to simultaneously measure boundary layer CO2 and an additional tracer, ideally carbon monoxide (CO). While this technology could ultimately benefit three of the decadal survey missions (ASCENDS, GEO-CAPE, and GACM), the implementation described here is tailored to support the specific requirements of the ASCENDS mission concept. An active (laser based) system will be used to detect CO_2 concentrations within a field of view approximately 110 meters in diameter at the ground. To be useful for ASCENDS, the CO concentrations must be measured at the same place, and the same time, with approximately the same field of view. Currently we are assuming 230 meters for the field of view for the CO measurement in our sensitivity calculations. Both the 4.7 and 2.3 micron channels will be required for the CO derivation, the 2.3 micron measurement is the more challenging and has not been demonstrated at (or even near) sufficient spatial and temporal resolution by any existing or developing instrument.



The passive instrument contains 4 channels providing: temperature information needed for the CO_2 retrieval from the laser data, coarse imagery to aid in cloud identification, and two infrared channels to provide the information required to distinguish CO in the upper and near-surface atmospheric layers. Both CO sensors can be built using our simple and robust COCOA design.

The relationship between CO and CO_2 concentrations is complex.

The figure below highlights the importance of CO measurements to the global carbon cycle and the assessment of CO2 sources and sinks. The data shown are in-situ CO and CO2 data measured onboard the NASA DC-8 over the southeastern US during the summer of 2004. This flight segment shows both strong correlations and anticorrelations between CO and CO2 ranging from the surface and upper troposphere (~12 km). This complexity arises from the seasonal uptake of CO2 by vegetation during summer in the presence of CO and CO2 from combustion sources. In the first boundary layer flight segment, CO and CO2 are strongly correlated, while the opposite condition exists in the following boundary layer segments. Under these conditions, the CO data is invaluable for assessing the importance of combustion sources relative to vegetative uptake on CO2 variability. Despite the large-scale anticorrelation in the third boundary layer segment, the importance of combustion sources can be seen in small-scale correlations between CO and CO2 within the larger segment. Similar anticorrelations in the upper troposphere such as in the third high altitude segment provide a valuable indicator of deep convection.

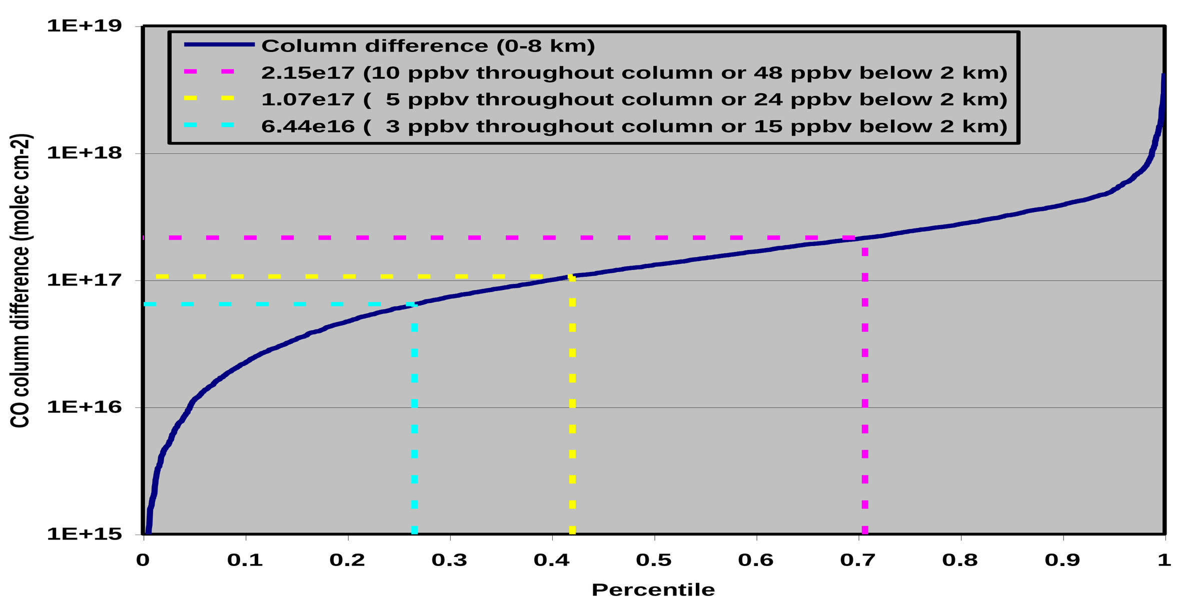


Time series of CO, CO2, and altitude measured from the NASA DC-8 during a flight over the southeastern U.S. during the summer of 2004. Measurements are from NASA Langley researchers (CO - G. Sachse and G. Diskin; CO2 – S. Vay). Note the numerous local scale correlations between CO and CO2.

For ASCENDS the CO and CO_2 measurements must coincide in both time and space.

The expected total column CO sensitivity required to identify man-made sources of CO_2 is ~5ppbv.

We have conducted a preliminary analysis of in situ measurements of CO from five commercial aircraft as part of the MOZAIC (Measurements of Ozone and water vapor by in-service Airbus aircraft) program. This program added CO to its suite of measurements in 2002. Data analyzed are from profiles sampled during take-offs and landings. The figure below shows short-term variability (one day or less) in CO column amount over all MOZAIC locations. This variability is represented by taking the difference between consecutive profiles separated by a day or less. The cumulative probability distribution of these daily changes in CO column provides a measure against which to assess a given sensitivity (shown by dashed lines) and the likelihood that the CO column change will exceed that sensitivity. Additional work examining seasonal behavior and relative variance in boundary layer and free tropospheric CO have also been conducted. These details can be found at www-air.larc.nasa.gov/missions/etc/COCOA.



Introduction

We have developed an instrument concept that will ***enable the measurement of CO*** from the top of the atmosphere to the Earth's surface with very high sensitivity and ***at the high spatial and temporal resolutions required by the*** **NRC** ***Decadal Survey mission Active Sensing of Carbon Dioxide (CO2) over Nights, Days and Seasons (ASCENDS).*** We are developing an innovative CO sensor that will enable the ASCENDS mission to differentiate between anthropogenic and natural sources and sinks of global carbon**.** The NRC Decadal Survey places particular emphasis on retrieving CO information for the planetary boundary layer. Measurement made using both the 2.3 micron and 4.7 micron channels are needed to achieve the sensitivity required in the lower atmosphere where the degree of CO - CO2 correlation is indicative of anthropogenic sources of CO2. Measurements made using only the 4.7 micron channel cannot provide sufficient sensitivity to CO in the very lowest layers of the atmosphere.

The fundamental method we use is Gas Filter Correlation Radiometry (GFCR), a highly successful technique used in other airborne and space-based missions for detecting trace species in the Earth's atmosphere. Our version of GFCR overcomes many of the limitations encountered by prior and existing instruments, allowing us to measure weak signals from small targets very quickly and with extremely high specificity by employing a new dual beam radiometer concept using a focal plane array. Our design will provide a means to make the desired CO measurements for the ASCENDS mission. A simple change in gas filter cell contents would allow the same hardware to measure CH4 with high precision under the nominal ASCENDS mission spatial and temporal constraints.

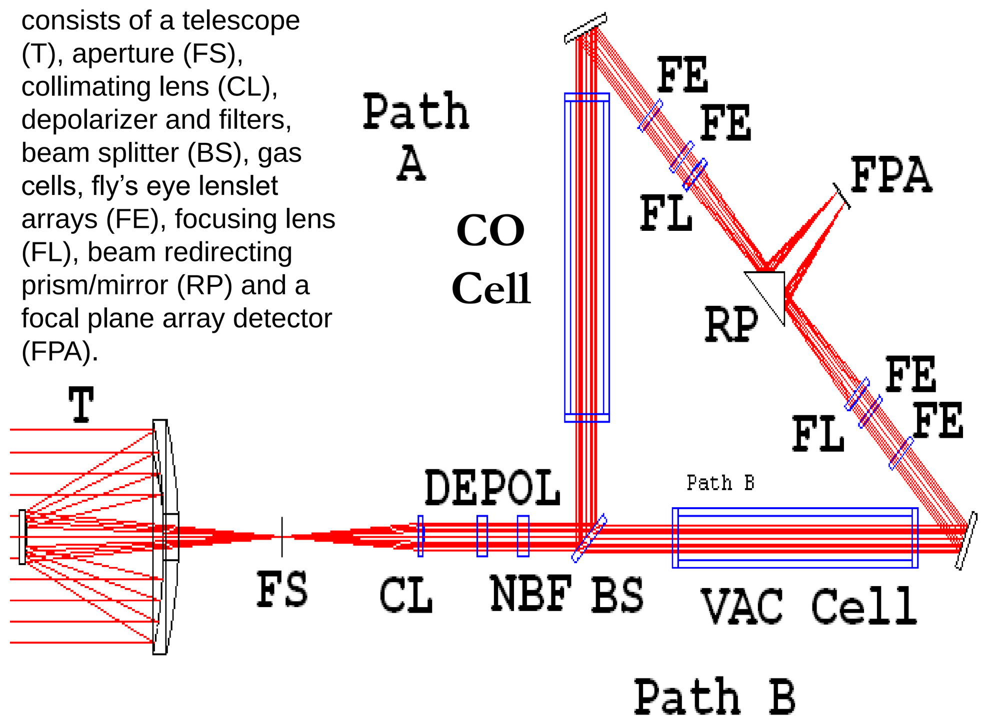
All critical components in the sensor design are mature, many subsystems tested, and the system has been extensively modeled, bringing it to a present Technology Readiness Level (TRL) of 3 (though some individual components are at TRLs 6-9). We are presently developing critical components for the new spectrometer and advancing our understanding of the measurement requirements for both CO and CH4. This new GFCR technique/sensor will enable measurements of trace gases with high sensitivity while maintaining the inherent robustness and simplicity of the more traditional radiometer hardware. Initial estimates of cost/risk of a space-based 2-channel GFCR indicate that our design is extremely cost effective and will fit within existing ASCENDS mission budget constraints as determined by the NRC Decadal Survey and a NASA-sponsored mission study.

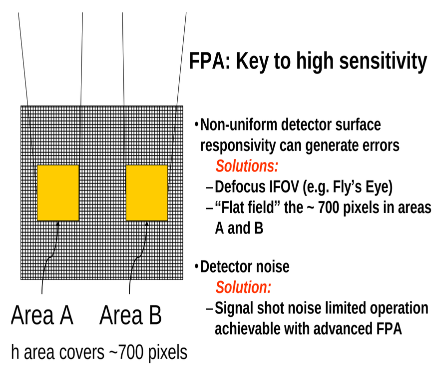
A dual beam, single array detector Gas Filter Correlation Radiometer is an accurate and highly cost effective way to measure CO at the temporal and spatial resolutions required for ASCENDS.

CO detection is based on the GFCR principle. The GFCR cell in path A (filter), labeled "CO Cell" in the figure, contains CO at a specific pressure and cell path length that significantly attenuates signals (information) from CO, yet allows the sensor signal in this path to still be almost completely sensitive to surface reflectance/emission, H2O(v) and CH4 effects. Path B (reference) contains an identical cell that is empty and is referred to as the vacuum (or "VAC cell"). With no spectral notch filtering, path B is sensitive to all parameters (reflectance, H2O(v), CH4 and **CO**). The difference signal ($D=S_A-S_B$) between the two paths is sensitive only to radiation coincident with each CO line. The sum signal ($S=S_A+S_B$) of the two paths is used to normalize the measurement and account for surface albedo changes. Once calibrated, the ratio D/S is a function of the atmospheric CO column.

In this way high spectral resolution (on the order of an atmospheric line width) is attained that results in high measurement specificity.

Our GFCR for ASCENDS consists of a telescope (T), aperture (FS), collimating lens (CL), depolarizer and filters, beam splitter (BS), gas cells, fly's eye lenslet arrays (FE), focusing lens (FL), beam redirecting prism/mirror (RP) and a focal plane array detector (FPA).





Separate simultaneous detection of the two beams eliminates many of the usual error-inducing effects related to changes in surface reflectance within the IFOV of a sensor during a measurement interval.

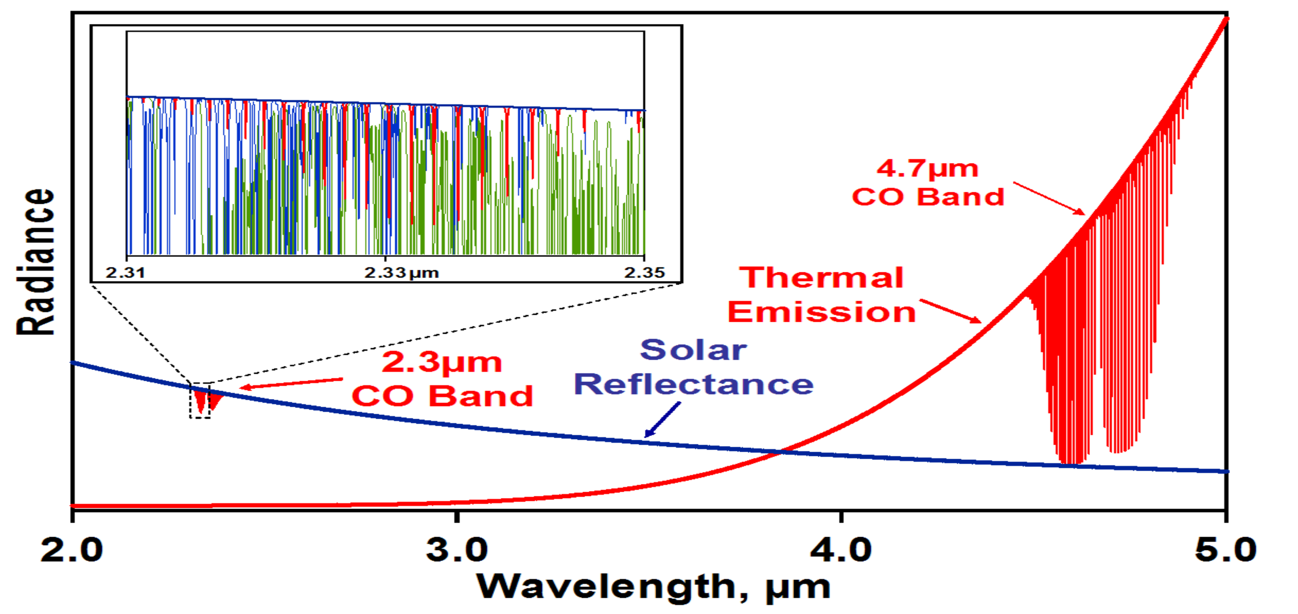
Predicted performance for CO

Calculated CO column precision in ppbv along a 100 km orbital path (nominal ASCENDS measurement.) The CO sensitivity derived from our GFCR instrument is 2 ppbv or better for all cases shown and for the actual operating resolutions required by ASCENDS.

Surface reflectance (2.3 μm)	Column precision Detector noise only (ppbv CO column)	Column precision $H_2O(v)$ error only (ppbv CO column)	Column precision CH_4 error only (ppbv CO column)	Column Precision Det. + Int. errors (ppbv CO column)
5% (vegetation)	1.8	< 0.5	< 0.8	2.0
10% (ground)	1.3	< 0.5	< 0.8	1.6
20% (clouds)	0.9	< 0.5	< 0.8	1.3
40% (desert)	0.6	< 0.5	< 0.8	1.1

The COCOA dual beam GFCR is expected to exceed the ASCENDS CO sensitivity requirement by a factor of 2 or more.

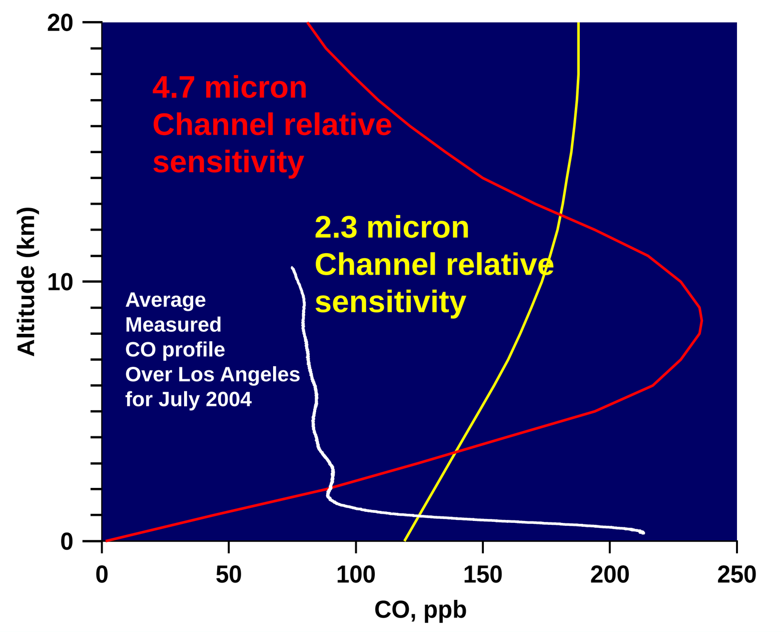
The atmospheric CO spectrum and effects of surface emission and solar reflectance



The figure above shows solar reflectance and thermal emission radiances viewed from space for the two CO IR absorption bands.

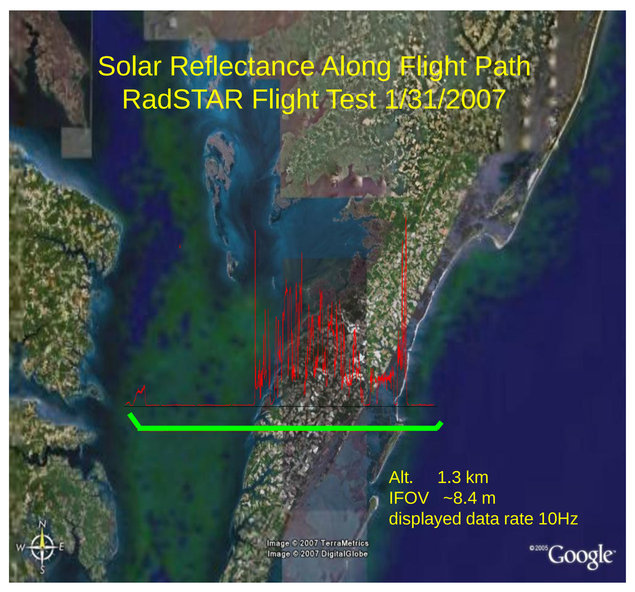
Measurement of the 2.3 micron band is essential for achieving the needed accuracy for lower atmosphere concentrations of CO.

The two CO spectral regimes offer different altitude sensitivity for remote measurements. In the 4.7 micron thermal emission band CO sensitivity peaks in the mid to upper troposphere where thermal contrast is greatest; but there is little PBL sensitivity due to low thermal contrast between the surface and the lower atmosphere. In the 2.3 micron reflected sunlight regime, thermal emission is negligible, resulting in sensitivity that is nearly constant with altitude. A simultaneous measurement using both bands provides CO profile information including an estimate of PBL CO.



For ASCENDS changes in the CO concentrations in the lower atmosphere must be measured with sufficient accuracy to identify correlations in CO_2 and CO caused by man-made sources. Given the temporal and spatial constraints of the ASCENDS mission and the nature of the atmospheric CO signal, this can only be done using the 2.3 micron band in conjunction with a 4.7 micron band measurement.

High variability in scene reflectance makes measurement of CO in the 2.3 micron band extremely challenging.



Changes in scene reflectance during measurement leads to a significant reduction in SNR in typical (sequentially measured) GFCR implementations since the background (evacuated) cell and CO cell measurements see different input intensities.

The COCOA GFCR's simultaneous CO and background measurement, collected by the same focal plane array, eliminates most of the error associated with reflectance variation.

Heritage of the GFCR

The MAPS and UARS/HALOE programs – examples of the heritage of NASA LaRC and GATS, Inc. in GFCR technology, space-based sensing and analysis – have made profound contributions to atmospheric science. MAPS, the first science payload on the Space Shuttle, provided man's first view of global tropospheric CO distributions and the global impact of pollution from space. HALOE was the first to observe trends in stratospheric chlorine and show conclusively that the main cause for ozone destruction was man-made chlorine.

Acknowledgements

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